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PRELIMINARY INVESTIGATION OF MECHANICAL RESPONSES OF FIBER OPTI--ETC(U)

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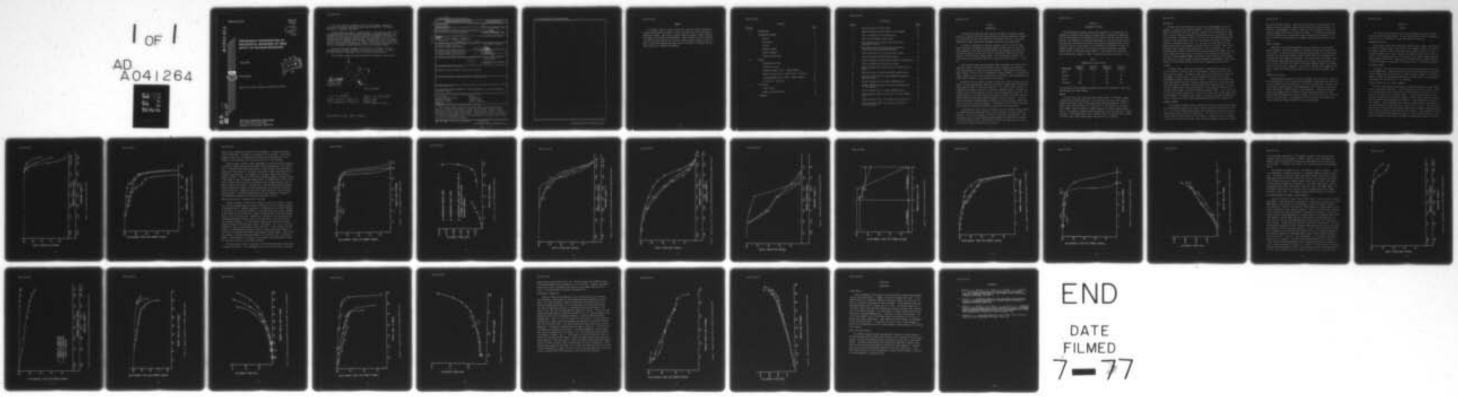

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PRELIMINARY INVESTIGATION OF MECHANICAL RESPONSES OF FIBER OPTICS TO NUCLEAR RADIATION

June 1977

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

AFWL-TR-76-291

This final report was prepared by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico under Job Order 88091124. The Project Officer is Lt Kenneth J Soda (ELPT).

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REPORT DOCUMENTATION PAGE

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14

1. REPORT NUMBER: AFWL-TR-76-291
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER: 9
4. TITLE (and Subtitle): 6 PRELIMINARY INVESTIGATION OF MECHANICAL RESPONSES OF FIBER OPTICS TO NUCLEAR RADIATION.
5. TYPE OF REPORT & PERIOD COVERED: Final Report,
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): 10 Capt J. C./Tucker, Lt K. J./Soda, Lt A. E. Mardiguian; A. E./; Kenneth
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Weapons Laboratory, Kirtland Air Force Base, NM 87117
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 62601F 8809 124 17 11
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Weapons Laboratory (ELPT), Kirtland Air Force Base, NM 87117 11
12. REPORT DATE: June 1977
13. NUMBER OF PAGES: 33
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 35p.
15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The experiments were performed by Mr Robert Lebduska of the Naval Electronics Laboratory Center.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fiber Optics	Neutron
Nuclear Radiation Effects	Electro Optics
Mechanical Stress	Optical Fibers
Fiber Optic Bundle	Optical Waveguides
Gamma Ray	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Four generic types of optical fibers which have low optical responses to nuclear radiation were evaluated to detect any significant radiation-induced mechanical changes. Bend radius, flexure, mandrel strength, tensile strength and thermal cycling tests were performed. Fiber responses in tensile and bending qualities were observed, but while the changes should probably be considered in application engineering, they are not significant in disqualifying any fiber from use in radiation environments.

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SUMMARY

Four generic types of optical fibers which have low optical responses to nuclear radiation were evaluated to detect any significant radiation-induced mechanical changes. Bend radius, flexure, mandrel strength, tensile strength and thermal cycling tests were performed. Fiber responses in tensile and bending qualities were observed, but while the changes should probably be considered in application engineering, they are not significant in disqualifying any fiber from use in radiation environments.

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SECTION I

INTRODUCTION

In previous programs under AFWL auspices and support, the Sandia Laboratories at Livermore, California have evaluated the optical responses of commercially-available optical fiber materials to transient radiation. The effects observed have been transient and permanent absorptions and luminescence.

This optical response work has been reported at the 1974 and 1975 IEEE Annual Conferences on Nuclear and Space Radiation Effects, the 76th and 77th Annual Meetings of the American Ceramic Society, the December 1974 meeting of the American Physical Society and the 1974 International Conference on Color Centers in Ionic Crystals, Sendai, Japan; it has also been published in the open literature and in Sandia reports (available through NTIS (refs. 1, 2, and 3).

Among the many commercially-available fibers evaluated, four generic fiber types were found to have radiation-induced optical responses small enough to allow consideration for some military applications. These fiber types were undoped synthetic vitreous silica (represented by Schott SUPRASIL I UV transmitting fiber), doped silica low loss (Corning Type B, 7940 Core), polymethylmethacrylate (PMMA, DuPont CROFON-6), and polystyrene (Polyoptics).

Besides the optical effects induced by radiation, Sandia and other previous workers noticed some apparent mechanical responses, including possible radiation-induced embrittlement of some fiber materials. This report conveys results of experiments performed at the Naval Electronics Laboratory Center. The work was funded by the Air Force Weapons Laboratory under Project Order AFWL-75-136. Mr. Robert Lebduska of the Naval Electronics Laboratory Center, Code 4400, designed and performed the experiments between September 1974 and June 1975. He evaluated the radiation-induced mechanical responses of the four generic fiber types having low optical radiation responses. The objective of this preliminary study was to determine whether more exhaustive evaluation would be required.

The quantitative tests chosen to indicate possible radiation-induced mechanical responses were minimum bend radius, flexure, mandrel strength and tensile strength. Qualitative responses to thermal cycling were also observed. These procedures should indicate radiation-induced mechanical properties or changes which might make the fibers unsuitable for military application or which might justify more extensive evaluation of the fibers.

SECTION II

EXPERIMENTAL METHODS

The experimental technique used was the comparison of the mechanical performance of irradiated fiber bundles (exposed either to neutrons or gamma rays) with the performances of unirradiated control samples from the same fiber lots. Because it was impractical to control and document all aspects of fiber material handling, the results are not intended to be absolute characterizations of the particular fibers or fiber cables. The experiments were designed to detect any changes induced by radiation as indicated by differences between irradiated samples and the unirradiated control samples. Cable bundles with differing fiber diameters and numbers of fibers per bundle were used (see table 1). Thus,

Table 1.

DIMENSIONS OF CABLES TESTED

Cable Type	Number of Fibers	Fiber Dia (mils)	Bundle Dia (mils)	Jacket Dia (mils)
Schott	95	3	40	80
Corning	21	5	30	90
DuPont	64	10	100	255
Polyoptics	425	5	135	190

one cannot make valid statements concerning the relative strength of these fiber bundles based upon these results.

SAMPLES

For each fiber type, there were three sample groups: unirradiated, gamma irradiated and neutron irradiated. The fluence and dose levels were chosen to produce significant levels of radiation-induced optical absorption. Neutron-sample fibers were irradiated to a fluence of 10^{14} neutrons/cm^2 (14 MeV equivalent fluence) from the Lawrence Livermore Laboratory's Rotating Target Neutron Source. This neutron irradiation was accompanied by less than 3200 rads of gamma radiation. Glass gamma-sample fibers received doses of 10 megarads from a Cobalt-60 source, while plastic gamma-sample fibers were given 1 megarad.

BEND RADIUS

The bend radius test consisted of winding one close-wrapped turn around mandrels of successively decreasing diameter. For glass and PMMA fibers, the number of continuous fibers was recorded. Because of the deformation of plastic fibers prior to breaking, photometric transmission data were recorded for PMMA and polystyrene. Photometric data for this test and those described below were obtained in the same manner as data from previous work performed at the Naval Electronics Laboratory Center (ref. 4). The results for Corning glass fiber bundles were found to be affected by constraint of the individual fibers within the bundle when a terminal was mounted within a foot of the bend site. This prompted separate testing of both constrained and unconstrained samples and testing of single fiber bend radius to discern any real radiation-induced effect. In testing of DuPont CROFON-6 (PMMA), the effects of the intimate contact between the fibers and the cable jacket prescribed photometric measurement of bend radius effects on fiber bundles without jackets and on comparable jacketed cables.

FLEXURE

In flexure tests, fibers were subjected to repeated bending between two circular mandrels. Bends of ±90° were performed at rates of one-half to one-third cycle per second. Photometric transmission was recorded as a function of the number of flexure cycles. To prevent mandrel tensile failure, fixture arrangements allowed a minimum constant tension. To prevent tensile loading of short cable samples from test fixturing, cable ends were cut to allow individual fibers the amount of freedom of relative motion which they would have in a more realistic sample length. Any work-hardening of cable jackets might develop a kink which would cause a much smaller effective mandrel radius. Only in the case of the Corning cables, supplied in a fairly stiff jacket, was special sample preparation needed. To separate jacket effects, a pliable length of shrinkable tubing was installed in place of the Corning-supplied jacket at the flexure site.

MANDREL STRENGTH

In the mandrel strength testing, photometric transmission data were recorded for fiber bundles subjected to a tensile load while bent 90 degrees around a mandrel. The mandrel diameters were chosen with consideration of each cable type's performance in bend radius and flexure tests. The diameters were two inches for Corning cables and one inch for all other cables. Loading was applied incrementally, with one minute hold at each load, and the photometric reading was taken at

the end of the hold interval. Steps were of one pound for Corning cables, two pounds for Schott and DuPont cables and four pounds for Polyoptics cables. In addition to the photometric readings, elongation data (expressed as percent increase in length) were taken for the DuPont cables. The observation that nearly all fiber ruptures were in the mandrel region indicates the importance of this test in addition to straight tensile strength tests described in the next paragraph.

TENSILE STRENGTH

Photometric and elongation data were used as indicators of fiber bundle tensile strength. Both were recorded as incremental tensile loads were applied to the fiber. To make any possible radiation-induced changes in the fibers more apparent, the Corning and Polyoptics bundle jackets were cut circumferentially to prevent tensile loading of the jackets. The rupture modes of the Schott glass fiber bundles showed that jacket loading was not a factor for this bundle type. For this test, the jacket and fibers of the DuPont CROFON-6 (PMMA) fiber bundles could not be effectively separated. Tensile force increments were generally two pounds, except for the polystyrene fiber for which four pound increments were used.

THERMAL CYCLING TESTS

Test exposures consisted of five cycles between -55°C and ±105°C. Except for the increased upper limit, the tests were conducted in accordance with Test Condition D, Method 102A of MIL-STD-202D. Each cycle included thirty minutes at the low extreme, fifteen minutes at room temperature, thirty minutes at the high extreme, and another fifteen minutes at room temperature. Preliminary tests indicated severe jacket material response for the polystyrene bundles; for these bundles the high temperature limit was relaxed to the +85°C specified in Test Condition D as cited above. The responses of the fiber bundles (including transmitted light) were observed qualitatively and photographed.

SECTION III

RESULTS

The results of the tests described in the preceding section are reported below for each fiber type tested. In some cases preliminary results suggested a variation of test conditions to assure the validity of the data.

PRESENTATION OF DATA

Where graphs of the three irradiation conditions for a single fiber material are shown in the same figure, the data will use a standard legend: the data for unirradiated samples will be plotted with square symbols; the data for neutron-irradiated samples with circles; the data for gamma-irradiated samples with triangles. This convention applies to all figures in this report except where separate legends are provided. Where a point is plotted with no symbol identifier, it should be taken as a super-position of points for all irradiation conditions.

PRECISION OF DATA

In general, the plotting of error bars with the graphs would not contribute to the presentation. The data were taken on limited sets and numbers of samples, and the intent of the study was only to identify possible trends. The narrative text will comment on the probable precision of the data where it is important in interpreting the information as it is presented.

UNDOPED VITREOUS SILICA - SCHOTT SUPRASIL I

The first four figures present data on undoped vitreous silica fiber cables. Figure 1 shows bend radius data. The curves are normal for glass fibers. There is a defined knee to each of the curves, indicating that the failure is principally in the stressing of individual fibers. The bend radius property has an apparent degradation with radiation. However, figure 2 shows an apparent improvement of mandrel tensile strength with radiation. These tendencies are mutually inconsistent. A pure experiment could separate these properties from effects of the jacket material and bend technique. That was not practical. The bend radius data are most strongly different at very small mandrel diameters where bend technique, tension and cable jacket materials are important. Gross differences due to radiation would have been expected to appear at larger mandrel diameters. Since these differences did not appear, the apparent degradation observed in the bend

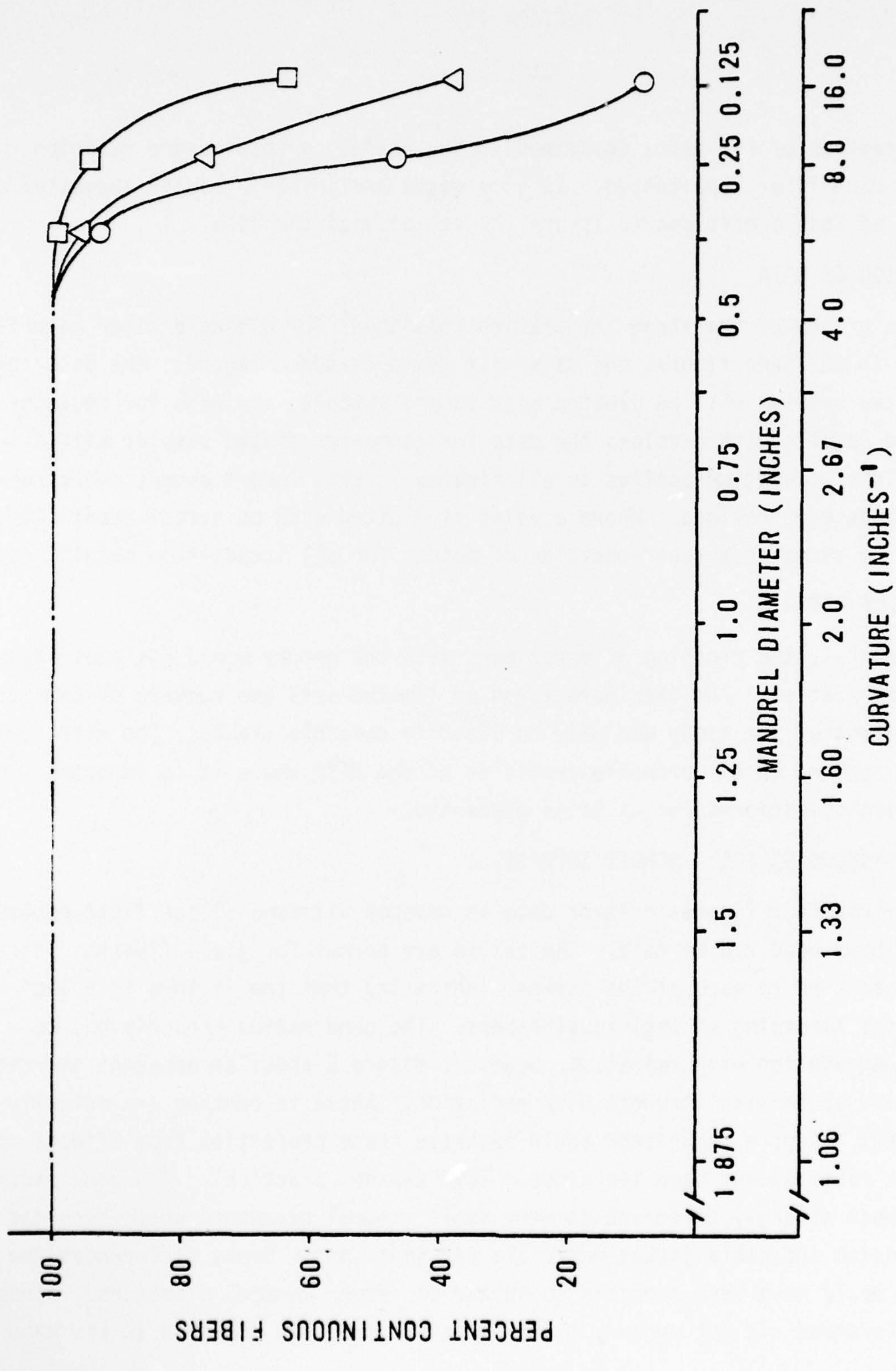

Figure 1. Bend Radius Test of Schott Cable.

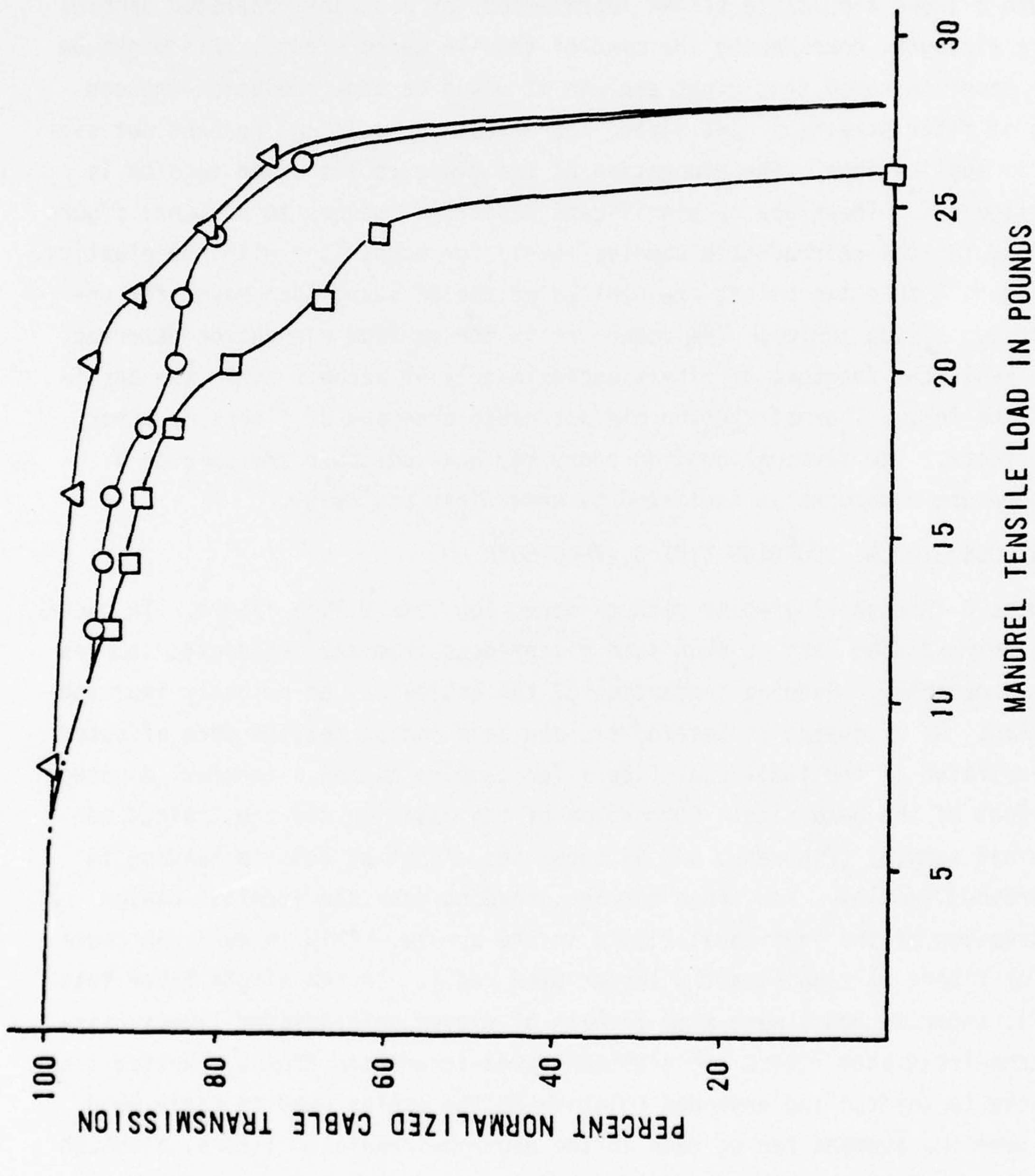

Figure 2. Mandrel Strength of Schott Cable (1 inch Mandrel).

radius data is probably an artifact of the experiment. It would not be practically significant. No figure is presented on the flexure data. After three thousand flexes on two inch mandrels and another three thousand on one inch mandrels at the same bend site, there was virtually no fiber breakage.

Figure 3 shows a possible slight improvement for neutron-irradiated samples in tensile strength; considering the mandrel tensile measurements, this might be real. (A possible model that might explain it would be some radiation-induced annealing of fiber strains.) But again, the effect is small and perhaps not significant in applications. The elongation of the glass cables under tension is shown in figure 4. There are no significant radiation changes to present; figure 4 shows data for the unirradiated samples mainly for comparison with the plastics. Note in figure 4 that two points are plotted at the 24 pound load point for undoped vitreous silica cables. The upper one is the maximum elongation observed before an avalanche fracture of fibers approximately 45 seconds after the application of the load. Thermal cycling did not cause breakage of fibers or other unusual effects. The terminal bonding epoxy may have softened and smeared at high temperature exposures as indicated by some fiber occlusion.

DOPED LOW LOSS SILICA - CORNING TYPE B, 7940 CORE

Figures 5 through 11 present data on doped low loss silica fibers. In general, the unirradiated samples show some differences from the irradiated samples of the same material. Bending properties of the cables may be slightly improved by radiation. As discussed in Section II, the bend radius results were affected by the constraint of the individual fibers for samples having a terminal mounted within a foot of the bend site. Comparison of the data for the constrained and unconstrained samples (figures 5 and 6) shows the effect of tensile loading in the constrained samples. For these samples, bending near the terminal causes uneven stressing of the individual fibers in the bundle. This in turn can cause breakage of fibers at significantly larger bend radii. In the single fiber test (figure 7), separate bends were made in each of eleven unirradiated fibers, sixteen neutron-irradiated fibers and eighteen gamma-irradiated fibers. Notice that the ordinate is shifted and expanded relative to the scales used in cable bend graphs. Some improvement can be seen in the neutron-irradiated fibers, although this may be an artifact of the bending procedure.

The flexure data (figure 8) show some possible radiation-induced improvement in mechanical response. This improvement may also be indicated by the responses

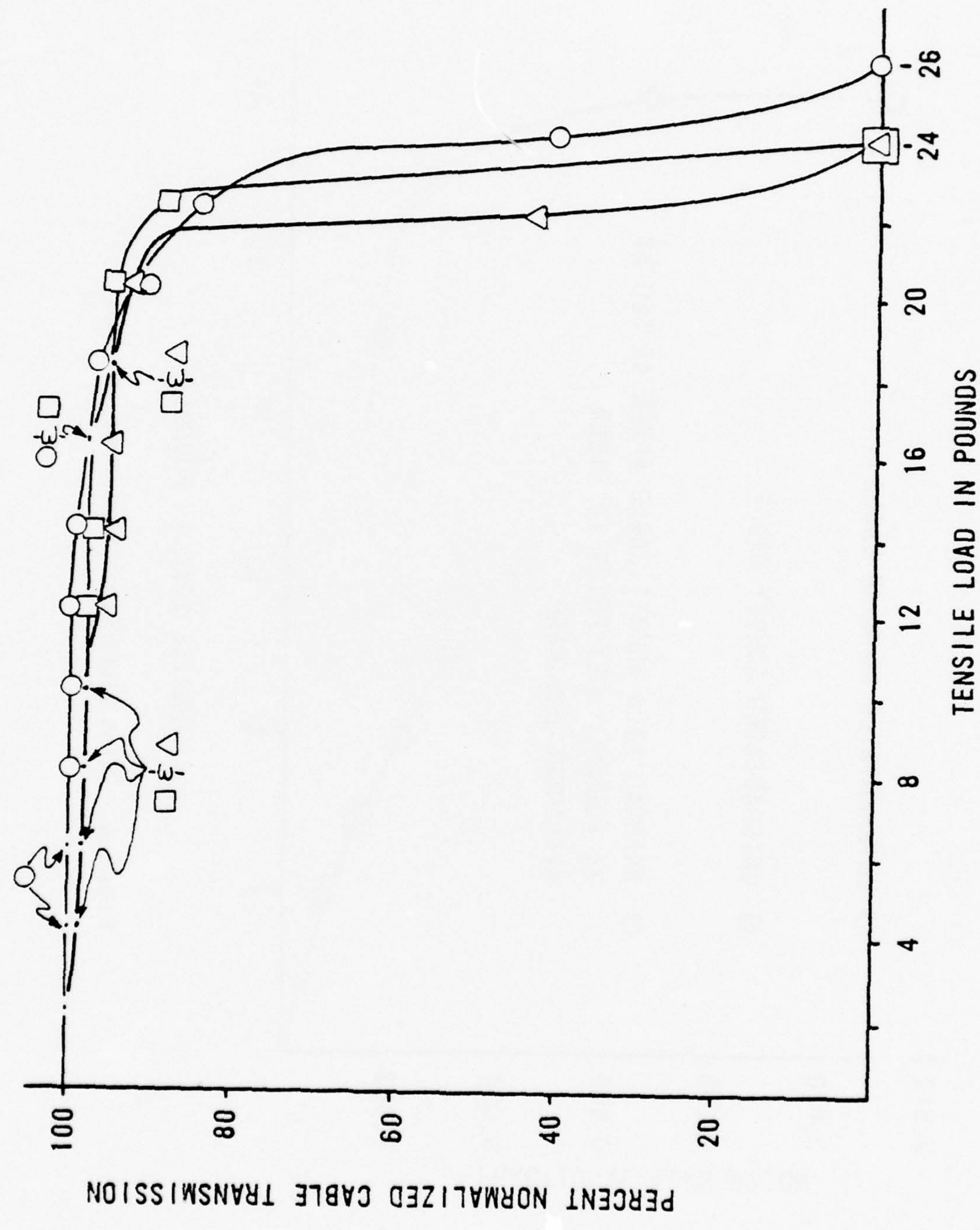

Figure 3. Tensile Strength Test for Schott Cable.

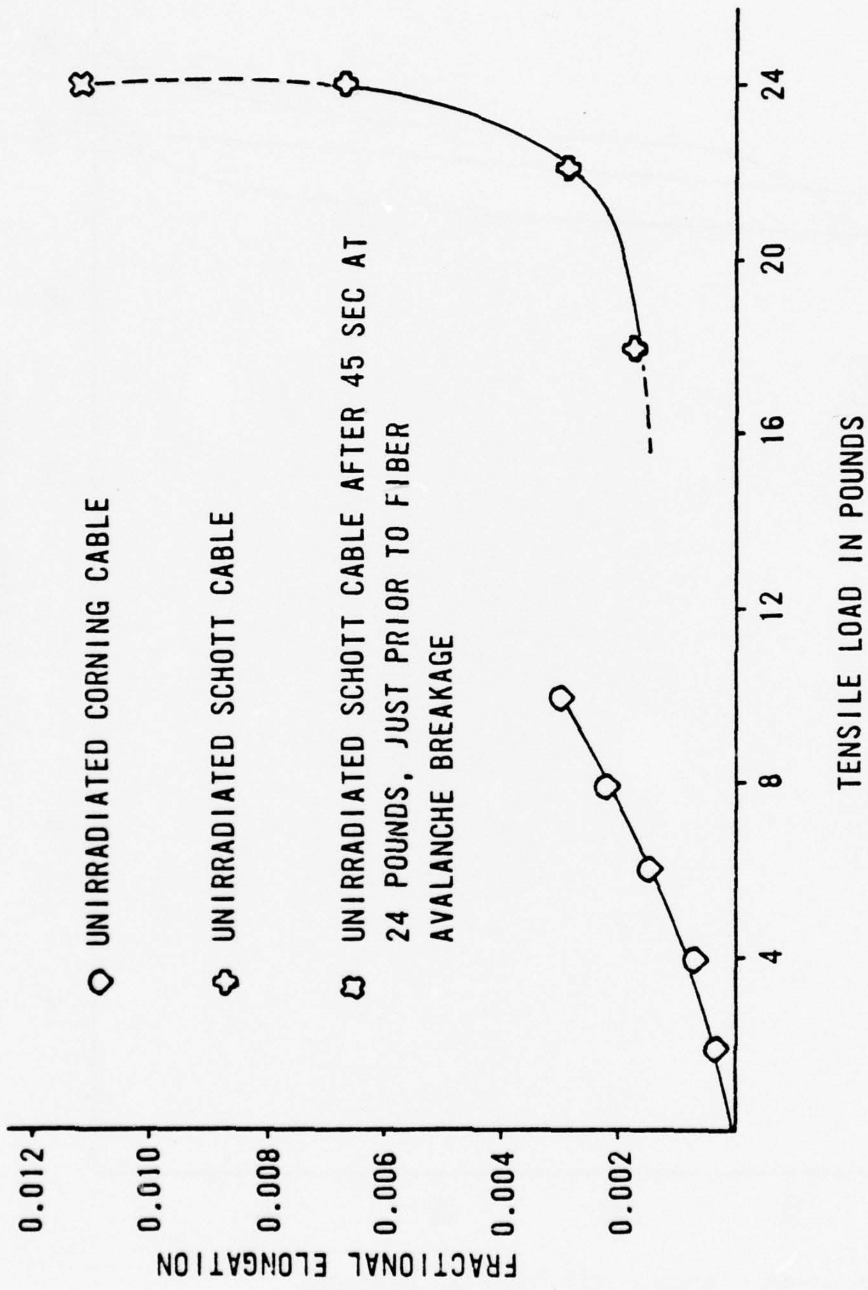

Figure 4. Glass Fiber Elongation Under Tension.

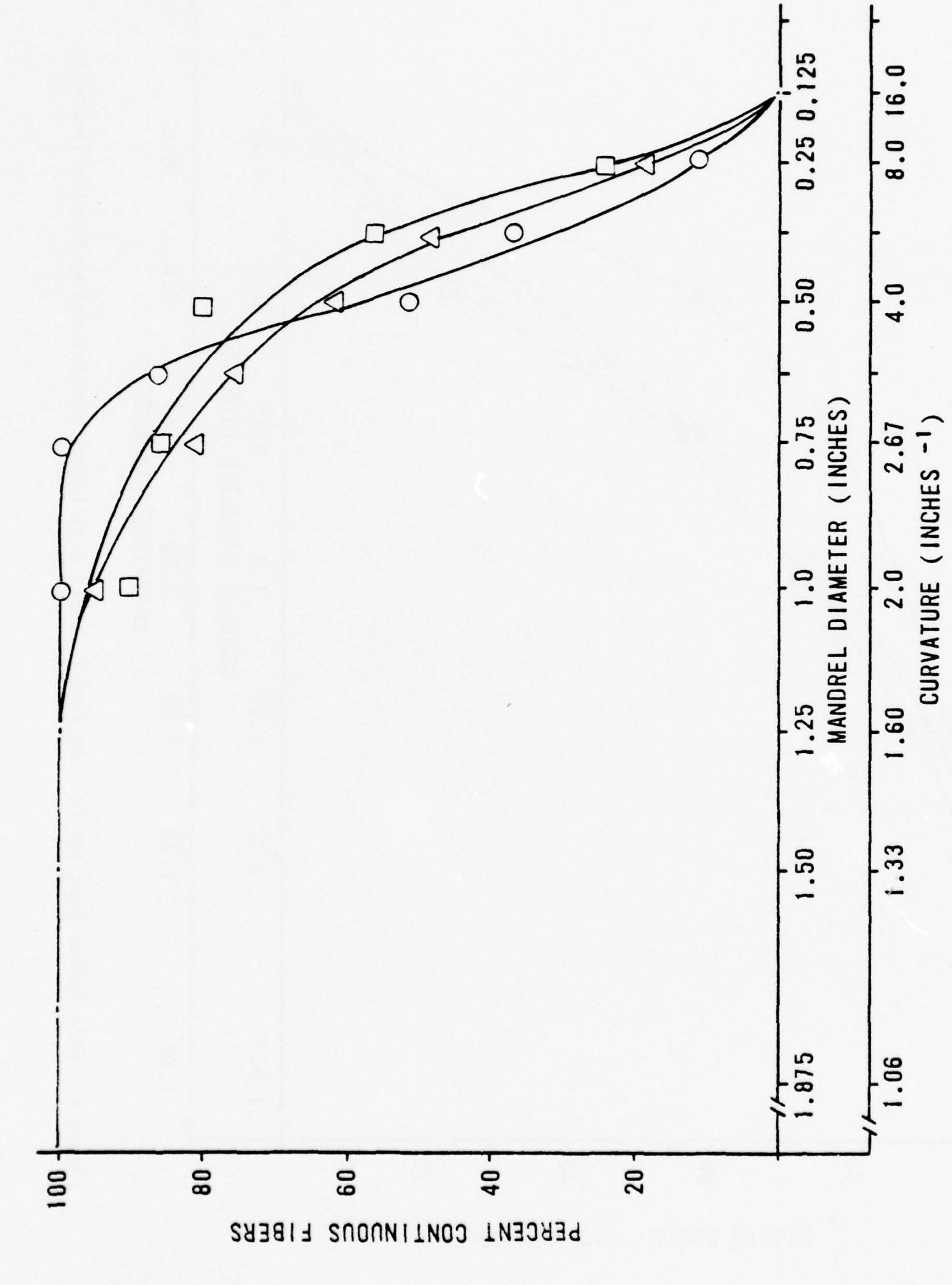

Figure 5. Bend Radius Test for Corning Type B Cables With Unconstrained Fibers.

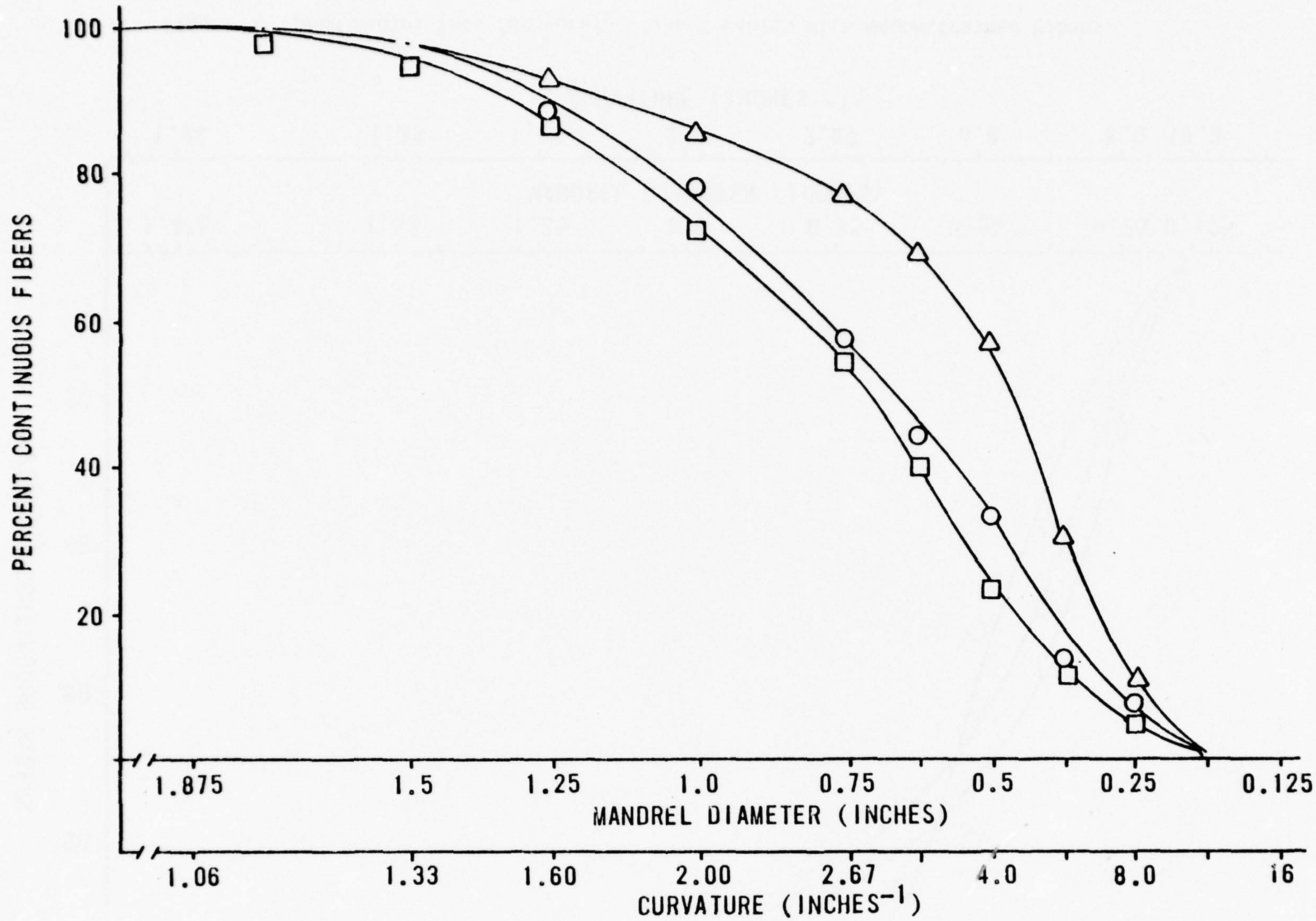

Figure 6. Bend Radius Test for Corning Type B Cables With Fibers Constrained by Mounted Terminals.

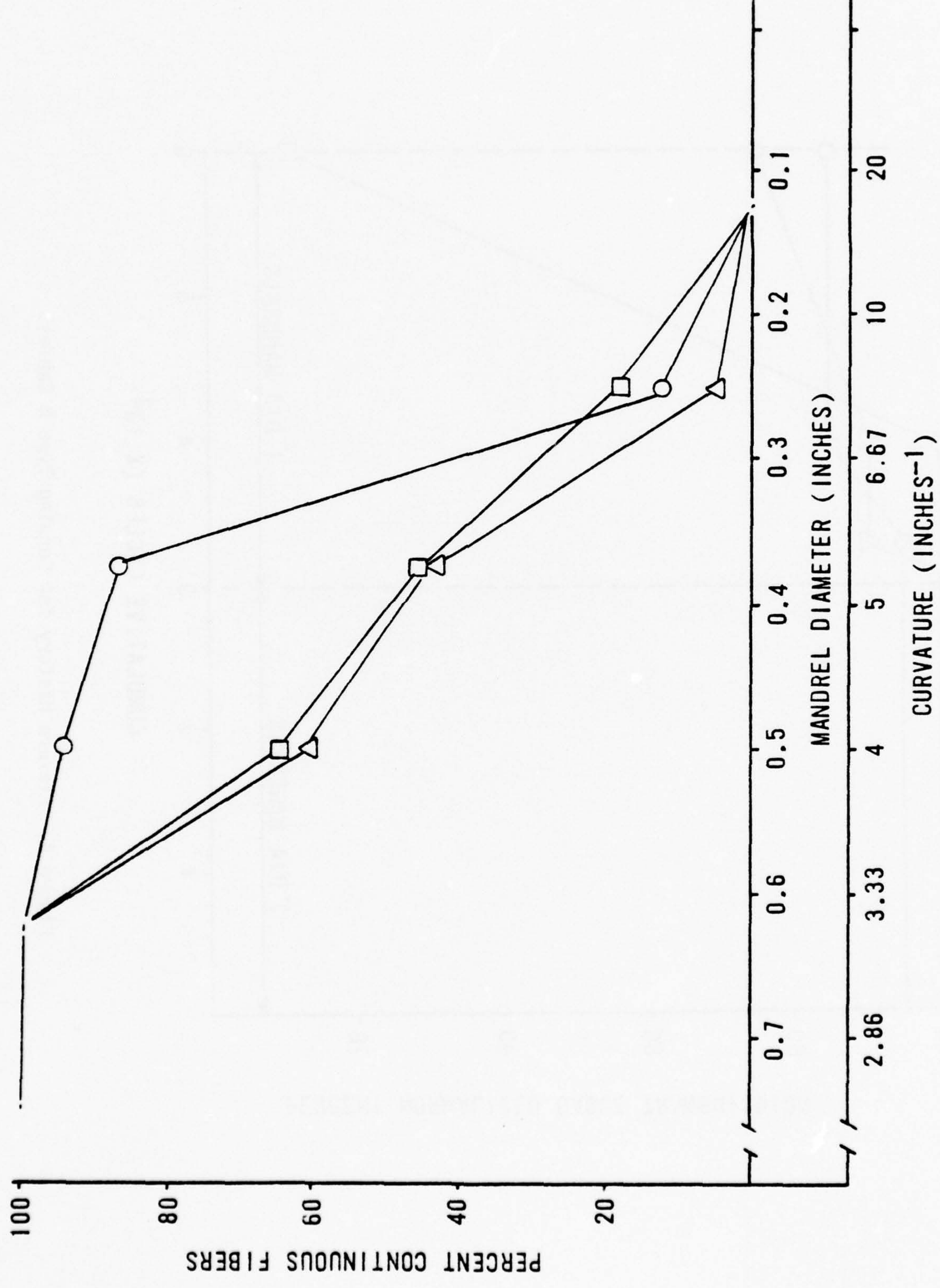

Figure 7. Single Fiber Bend Test of Corning Type B Fibers.

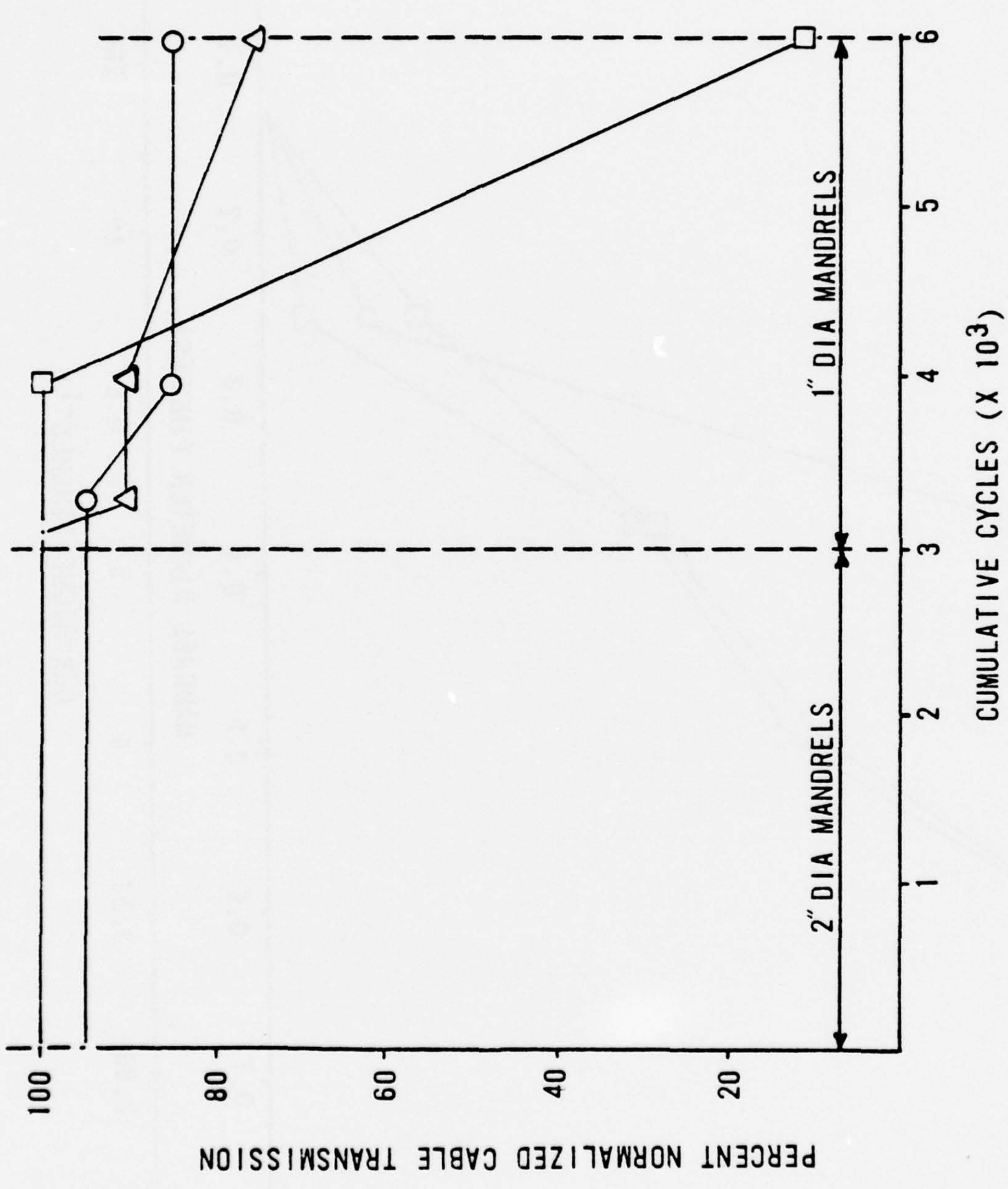

Figure 8. Flexure History for Corning Type B Cables.

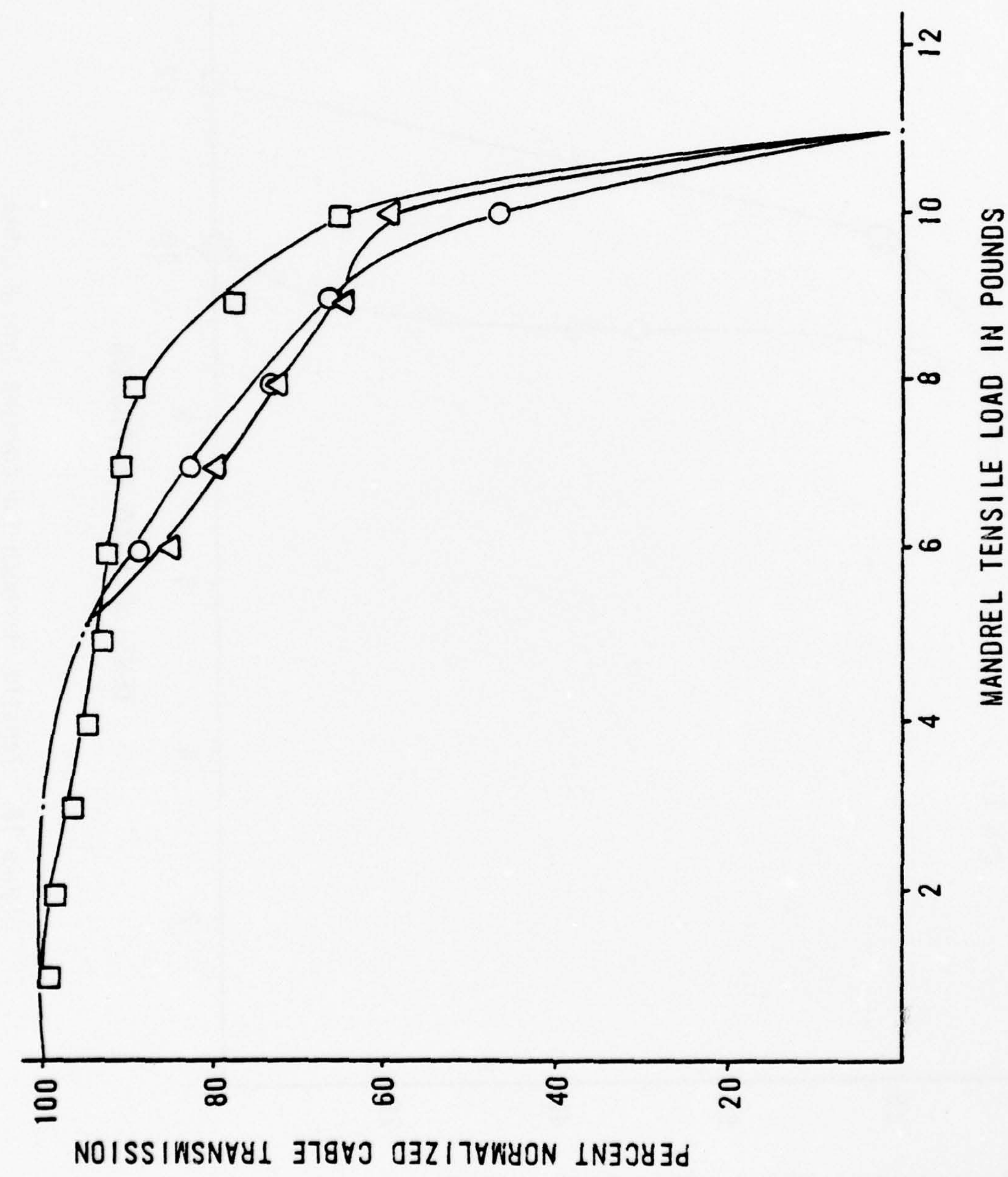

Figure 9. Mandrel Strength of Corning Type B Cable (2 inch Mandrel).

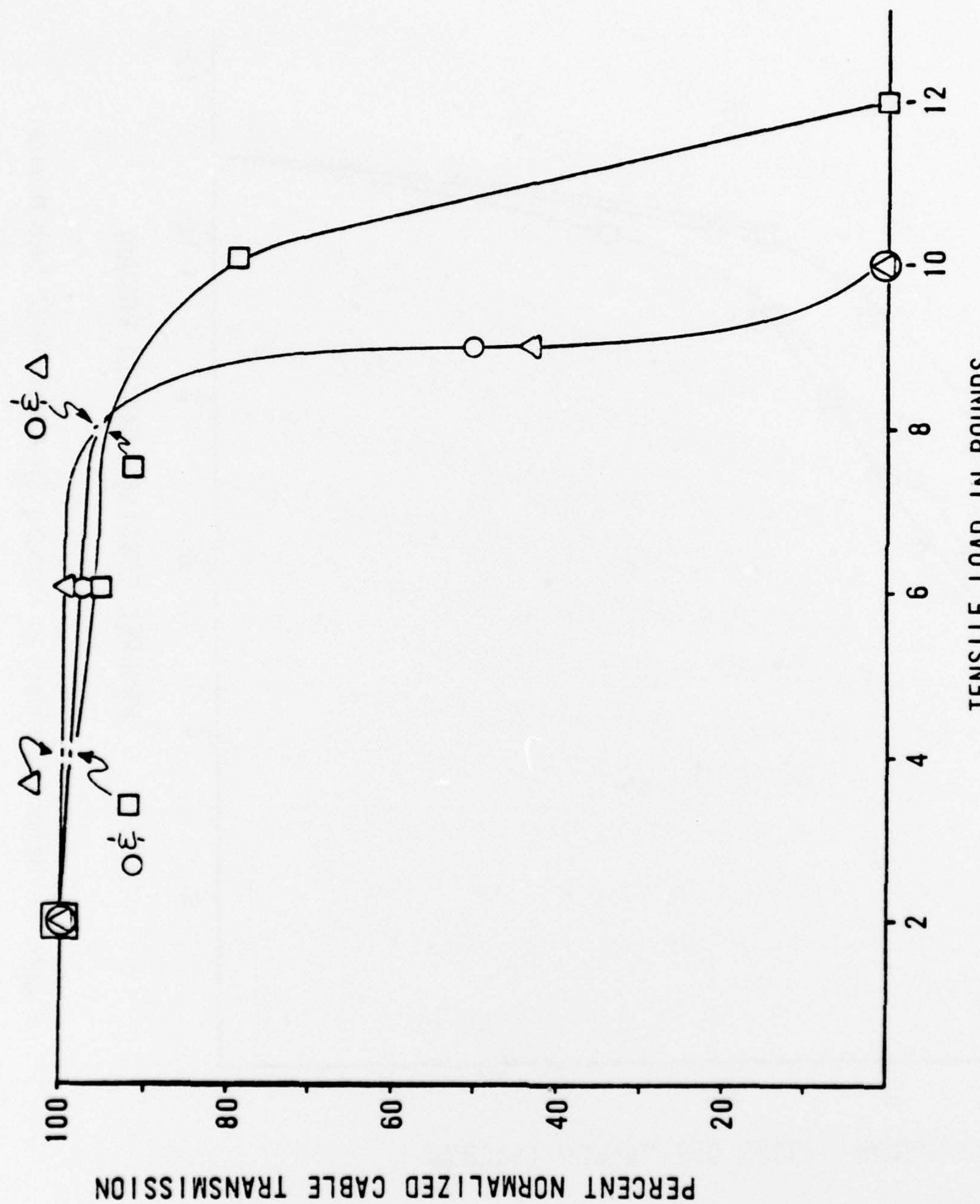

Figure 10. Tensile Strength for Corning Type B Cable.

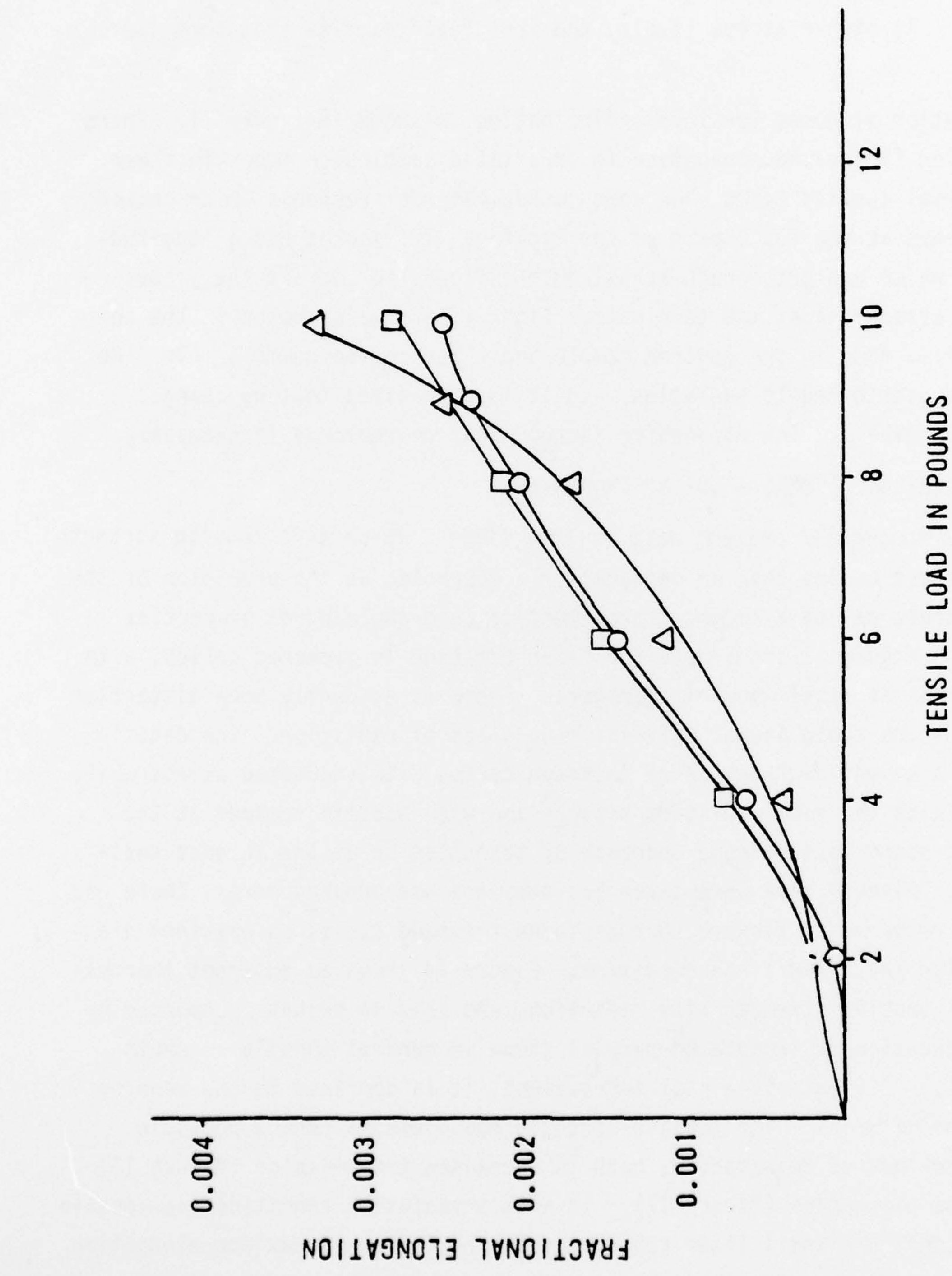

Figure 11. Cable Elongation Under Tensile Load for Corning Type B Cables.

visible at lower stress levels in the mandrel strength (figure 9) and tensile strength (figure 10) measurements. However, these low stress differences are probably within manufacturing variations and experimental accuracy, and hence not meaningful. At higher stress levels, the irradiated samples show some degradation.

The elongation of doped low loss silica cables is shown in figure 11. There is no degradation (increased elongation in irradiated samples) evident in these data. The thermal cycling tests show some jacket material response which caused some broken fibers at the 105°C part of the cycling. The jacket has a longitudinal shrinkage which can put enough stress on the fibers to retract the jacket from the epoxy attachment at the terminals. Eight fibers were broken in the unirradiated sample, four in the neutron sample and three in the gamma sample. No differences are attributed to radiation, and it is emphasized that no changes were seen in the fibers. The responsive jacket might be replaced if necessary.

POLYMETHYLMETHACRYLATE (PMMA) - DUPONT CROFON-6

Figures 12 through 17 present data on PMMA fibers. Except in tensile strength measurements, these cables show no degradation. Depending on the precision of the measurements, there may be a slight improvement of bend and mandrel properties with radiation. Figure 12 shows data for fiber breakage in jacketed cables, with slight differences at small mandrel diameters. There is evidently some distortion of the fibers by the cable jacket material regardless of radiation. The data in figure 13 show a steady degradation of jacketed cables with increased stress while fiber bundles (with the same radiation history and with jackets removed at the bend site) just start to show some decrease of transmission at the largest testable curvature. Flexure data were taken but they are not graphed here. There was no measureable response to flexure through three thousand cycles on one inch diameter mandrels for any irradiation condition. Figure 14 shows an apparent improvement of mandrel tensile strength with radiation, and this is perhaps supported by the reduced elongation of irradiated samples shown in mandrel tensile strength tests (figure 15). If this is a real improvement, it is confined to the bending qualities of the material. The tensile strength measurements show a possible slight radiation-induced degradation, both in decreased transmission (figure 16) and in increased elongation (figure 17). In each irradiation condition the tensile strength test continued until fiber rupture avalanche failure. Maximum elongation is about thirty times that for glass fibers (figures 4 and 11) and almost four

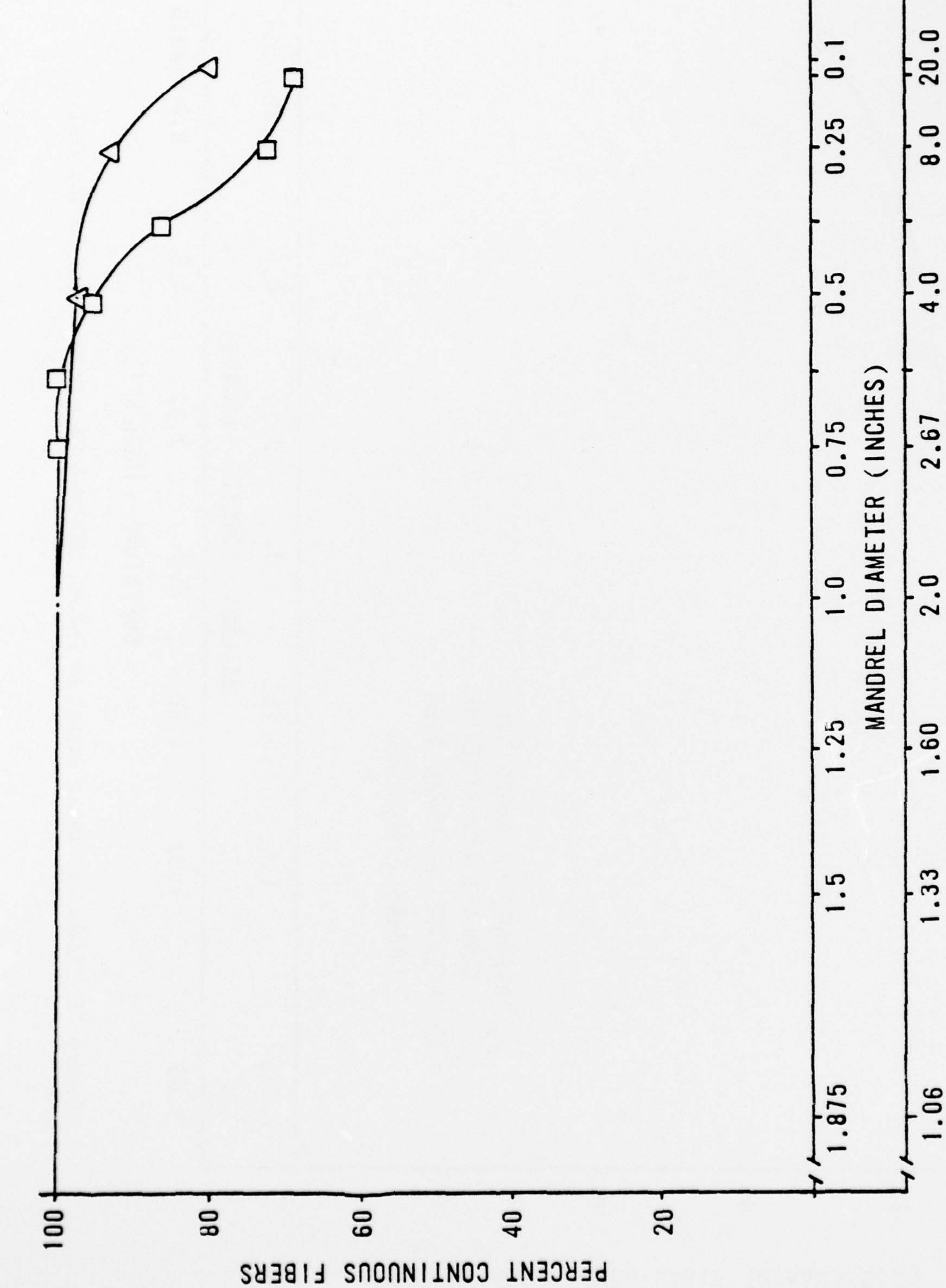

Figure 12. Bend Radius Test for DuPont CROFON-6 Jacketed Cables.

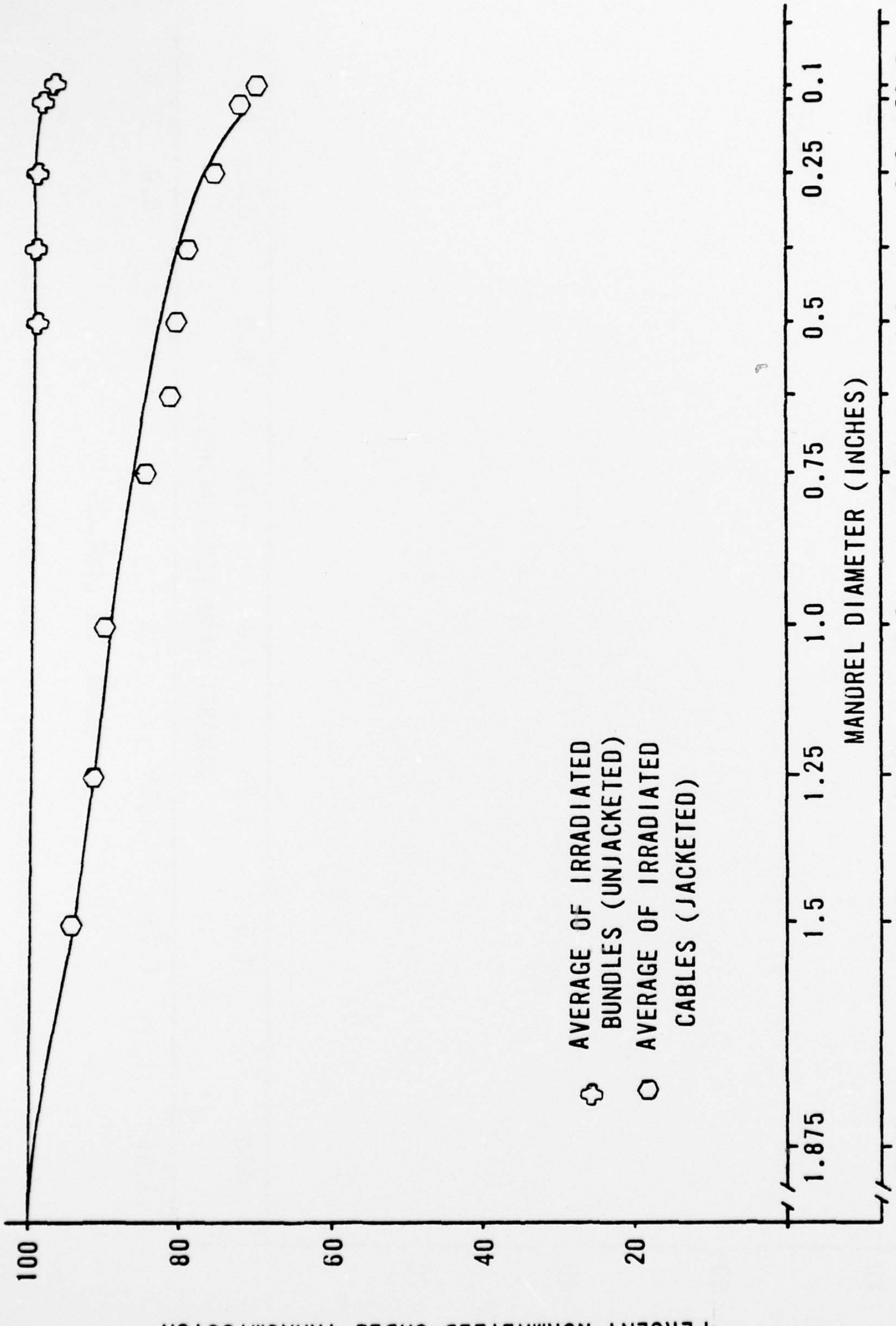

Figure 13. Effect of Cable Jacket on DuPont CROFON-6 Photometric Bend Radius Test.

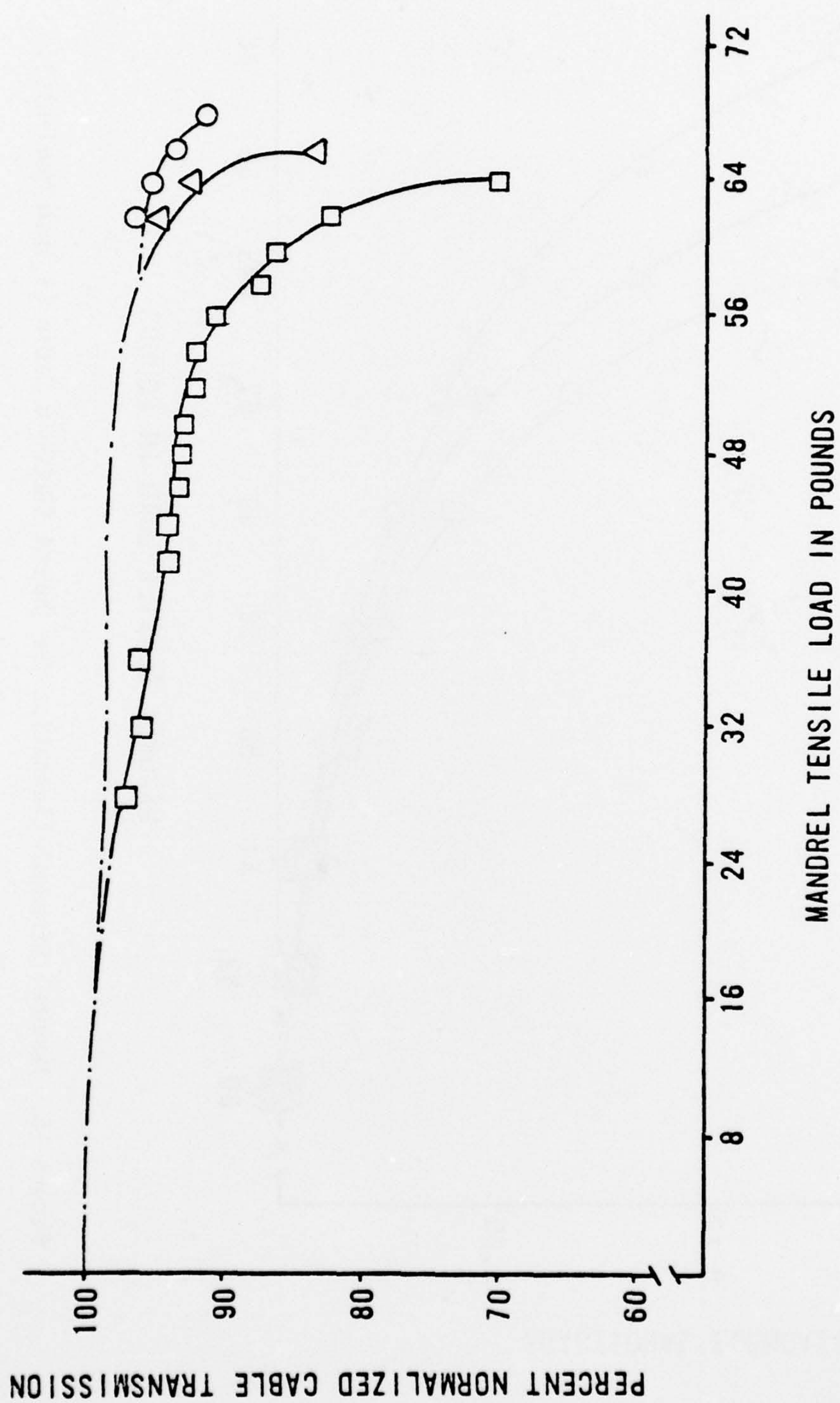

Figure 14. Mandrel Strength Test for DuPont CROFON-6 Cables.

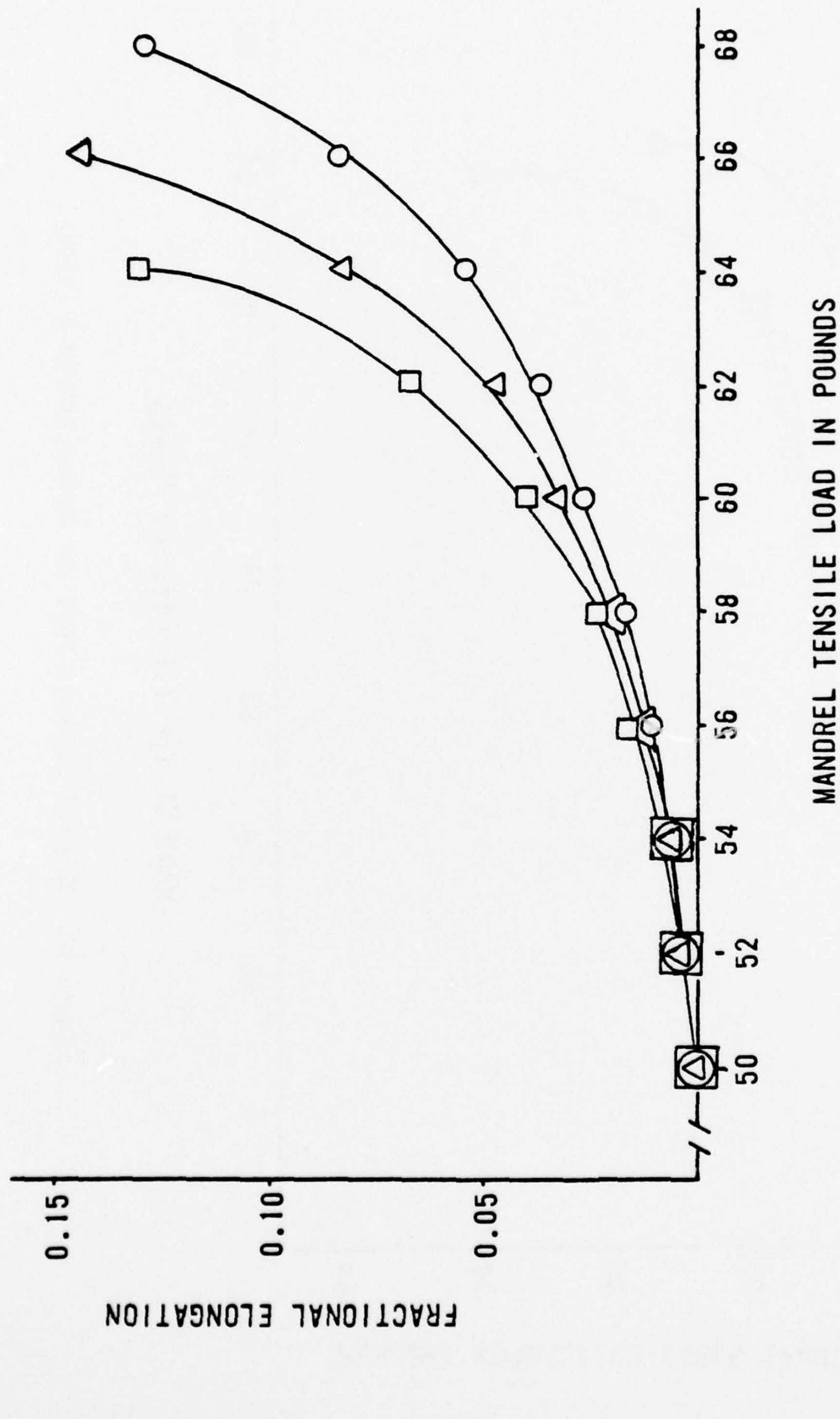

Figure 15. Mandrel Strength Elongation for DuPont CROFON-6 Cable (1 inch Mandrels).

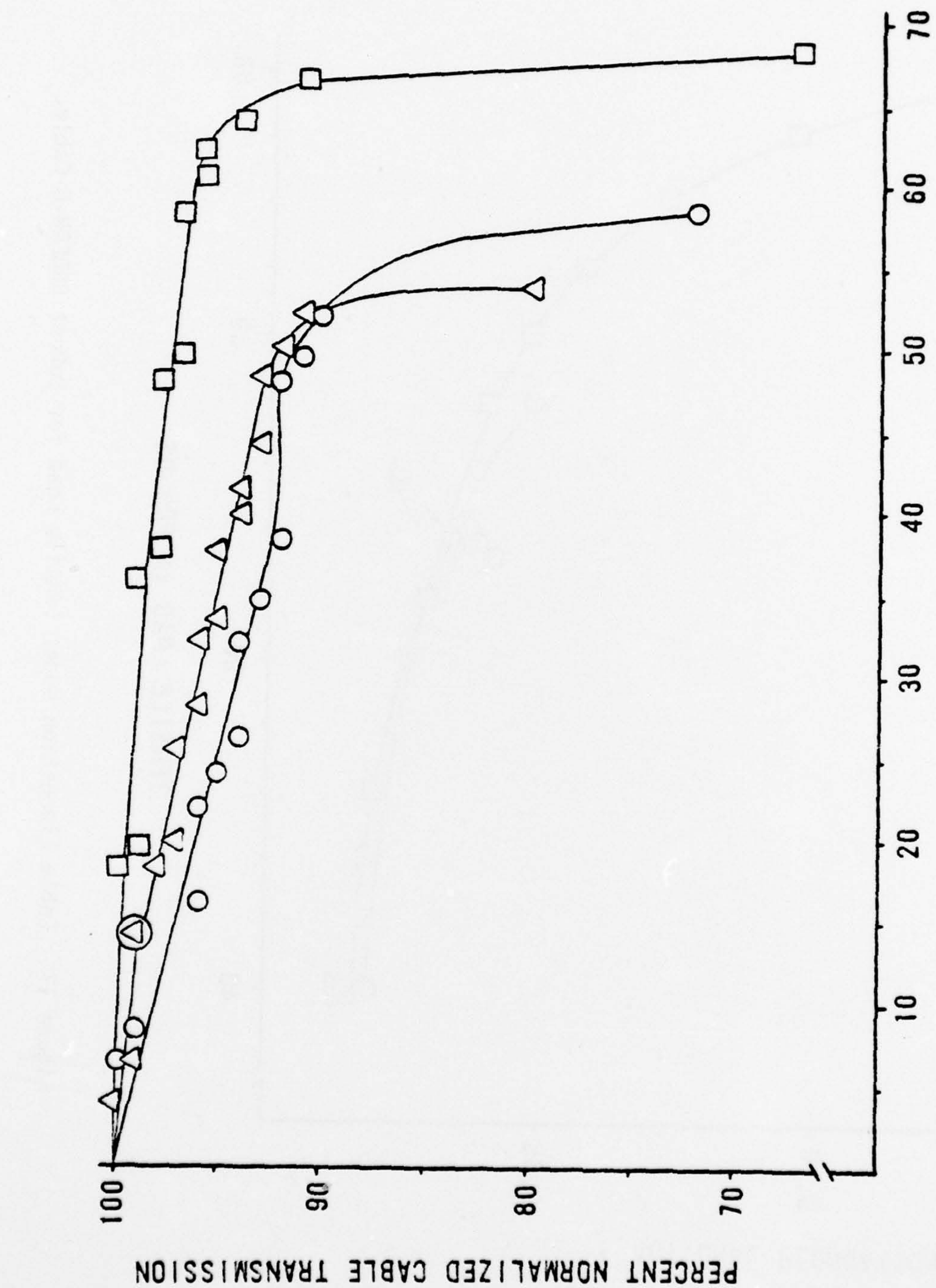

Figure 16. Tensile Strength Test for DuPont CROFON-6 Cables.

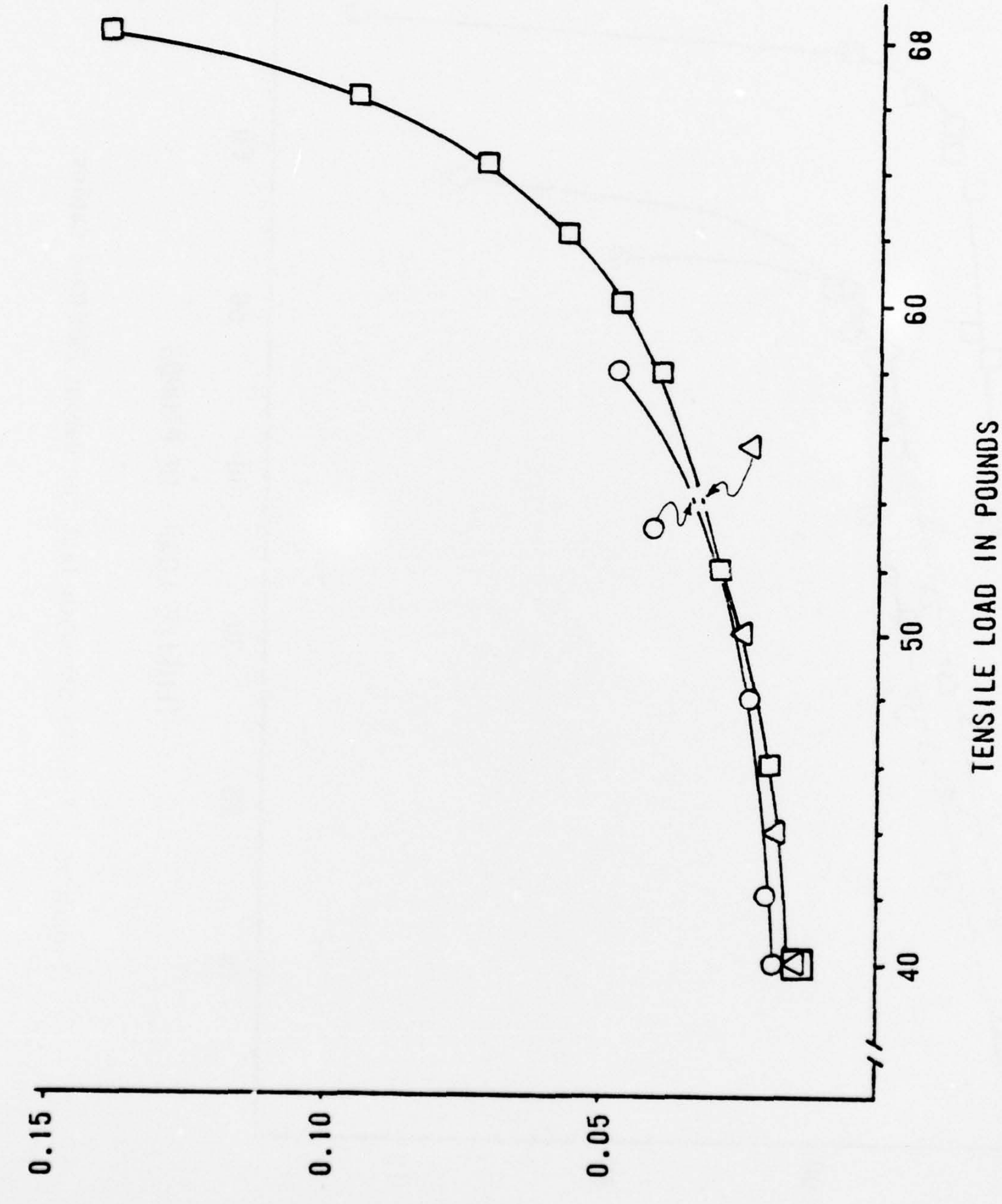

Figure 17. Cable Elongation Under Tensile Load for DuPont CROFON-6 Cable.

times that for polystyrene (figure 19). Thermal cycling tests showed no radiation-induced changes, and no changes at all in the fibers. However, the temperature cycling led to shrinkage of the jacket, causing some stressing of the fibers. The jacket material retained a permanent "set".

POLYSTYRENE - POLYOPTICS

There are fewer graphs presented for the polystyrene than for the other fiber materials. Many graphs for polystyrene would be uninformative straight lines. All samples showed no change in normalized transmission down to the smallest testable bend radius (0.1 inch) regardless of irradiation condition. This does not mean that there was no radiation-induced optical damage. The physical test just did not reduce optical transmission further. The flexure test showed one hundred percent normalized transmission for all samples through three thousand cycles on one inch diameter mandrels. Figure 18 shows the mandrel strength data. There is a loss of transmission with stress. This was caused by deformation of fibers rather than breakage, and there was no significant difference for irradiated fibers. The neutron sample test was curtailed by a terminal separation. The tensile elongation data are shown in figure 19. No significant differences of elongation are apparent. All samples approach a value of about four percent elongation prior to rupture. This can be compared with elongations for glasses in figures 4 and 11. The thermal cycling tests showed no fiber responses or radiation-induced changes. However, dramatic effects were seen due to jacket response. After one cycle to +105°C, the samples were contracted to about one-half of their original length, and there was no optical transmission. Other samples were tested with the upper limit of the cycle lowered to +85°C, and little of this contraction was noted. The +85°C limit is the same specified in Test Condition D, Method 102A of MIL-STD-202D on which the test was patterned.

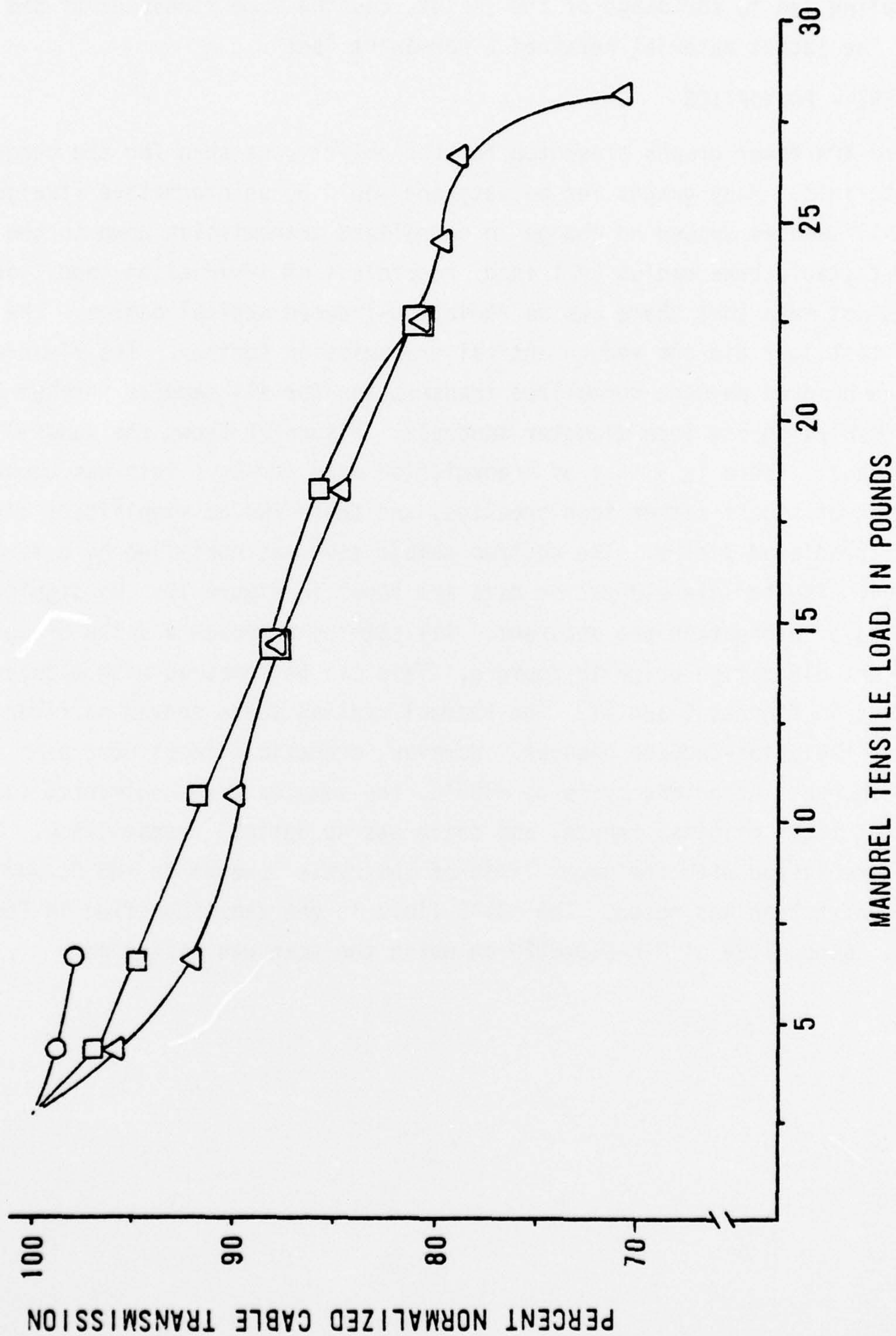

Figure 18. Mandrel Strength Test for Polyoptics Polystyrene Cable.

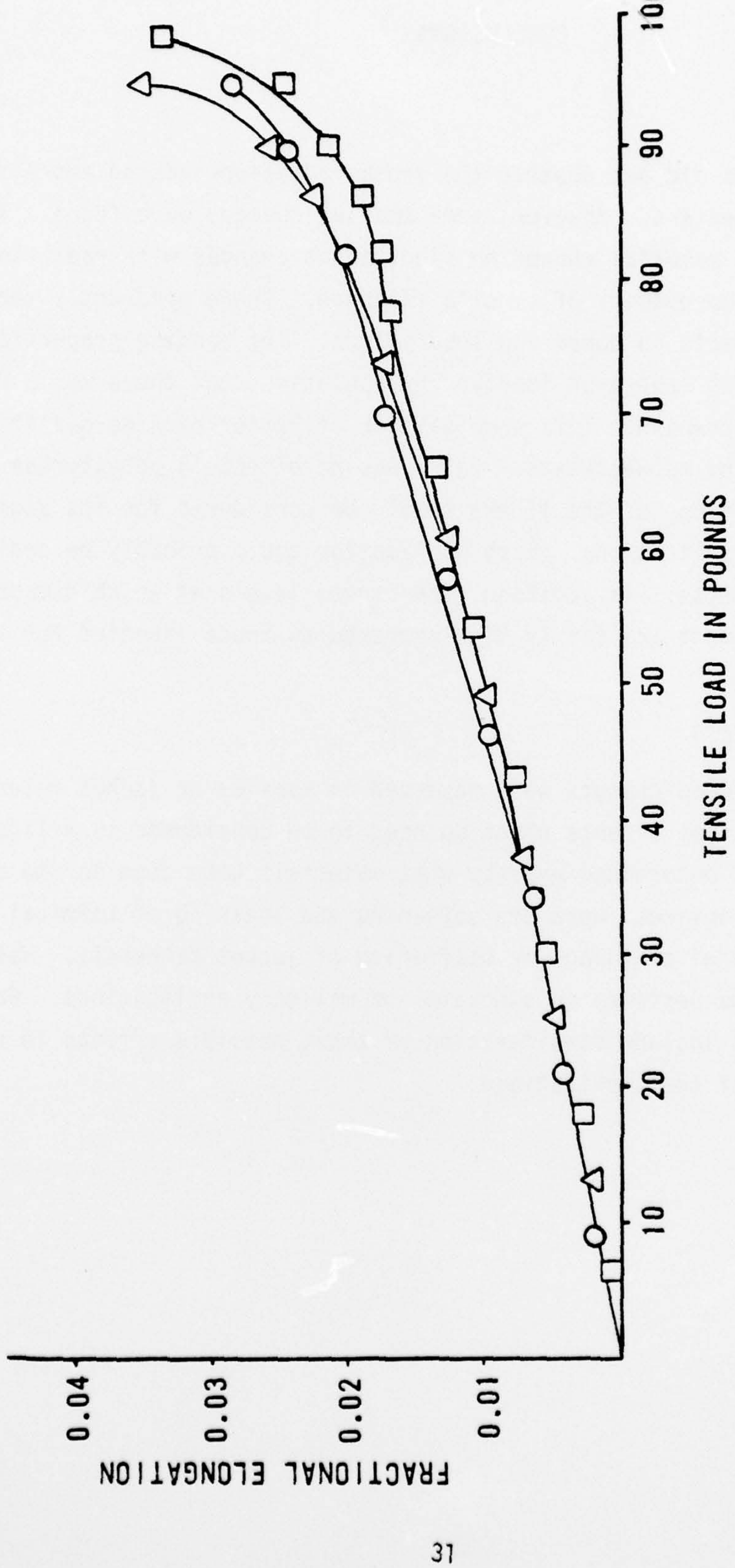

Figure 19. Cable Elongation Under Tensile Load for Polyoptics Polystyrene Cable.

SECTION IV

CONCLUSIONS

FIBER EFFECTS

These experiments did not observe the gross radiation-induced embrittlement seen by other experimenters. However, some smaller changes were found. The undoped vitreous silica material showed no significant changes with radiation except for a possible improvement of tensile strength. There apparently were some radiation-induced effects in doped low loss silica. The bending properties of individual fibers might have been improved by radiation, but there was a degradation of the tensile strength. This same pattern of better bending qualities was seen again in polymethylmethacrylate. There was no effect in polystyrene. The size of the changes in any of the fibers should be considered for its significance in particular applications. Each application could probably be engineered to minimize these effects. In addition, the stress levels at which damage occurred in this experiment are fairly high compared to those expected for installed fiber cables.

EPOXY AND JACKET EFFECTS

No radiation-induced changes were observed in epoxies or jacket materials, but there were mechanical effects which do need to be considered in military applications. We have not determined exactly what materials were used in the samples tested. The effects observed were the softening and smearing of terminal bond epoxies and longitudinal shrinkage or stiffening of jacket materials. Materials exist which do provide performance adequate for military applications. Cable specifications should include consideration of these possible effects in relation to the requirements of the applications.

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